Astrophysics Enabled by the Return to the Moon

"One's Destination is never a place but rather a new way of looking at things."
– *Henry Miller*

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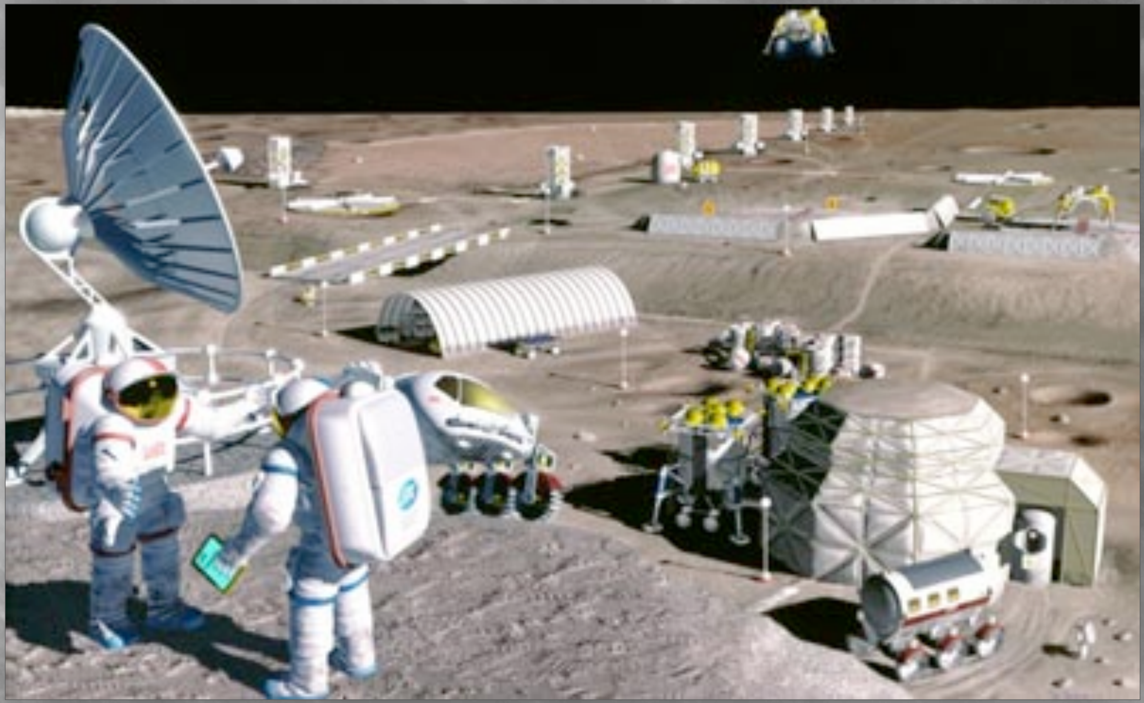
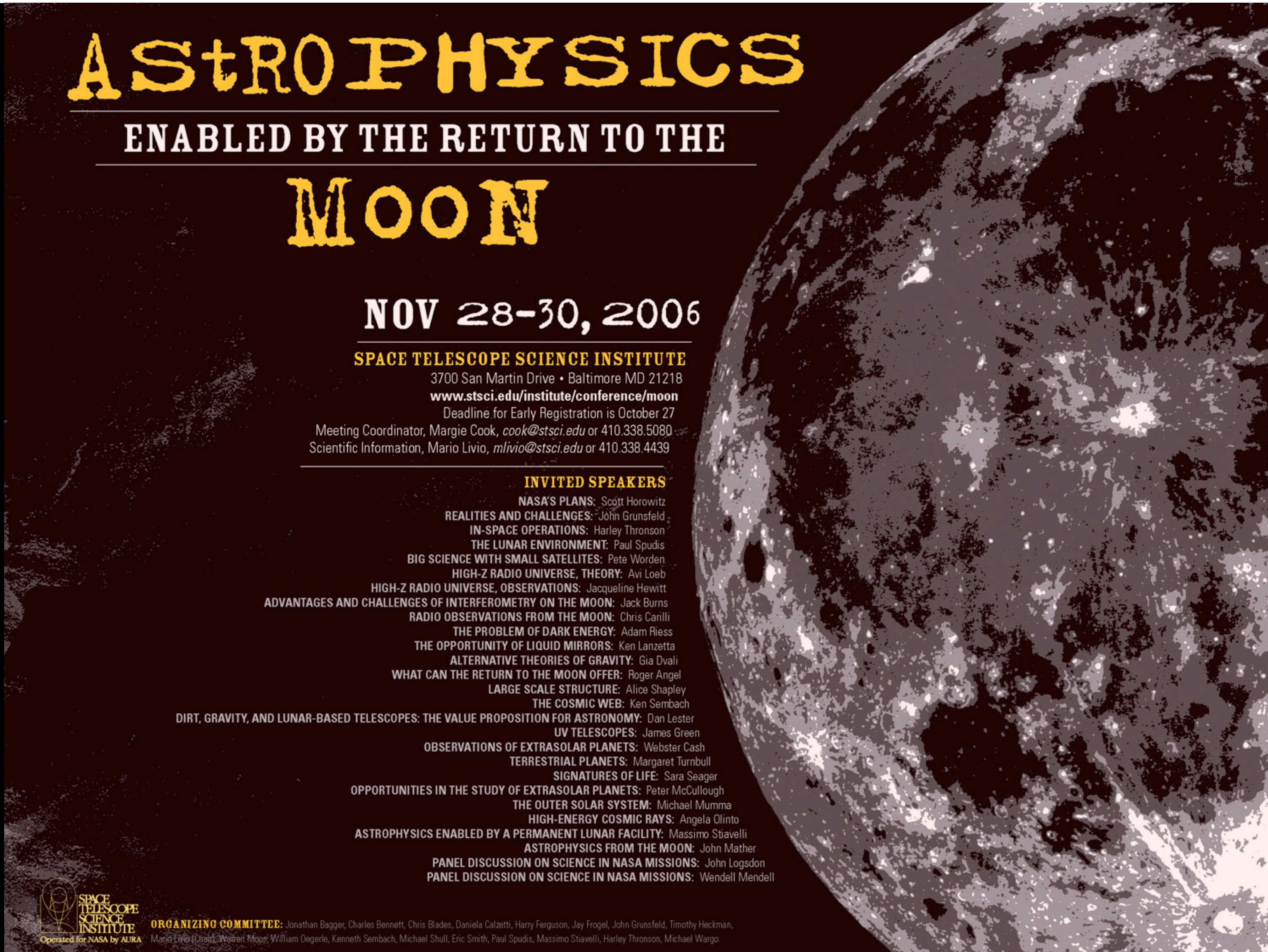
Space Telescope Science Institute

BRIEF OUTLINE

- What are some of the major questions in astrophysics?
- How can the VSE address these questions?
- Smaller-scope experiments.
- Conclusions

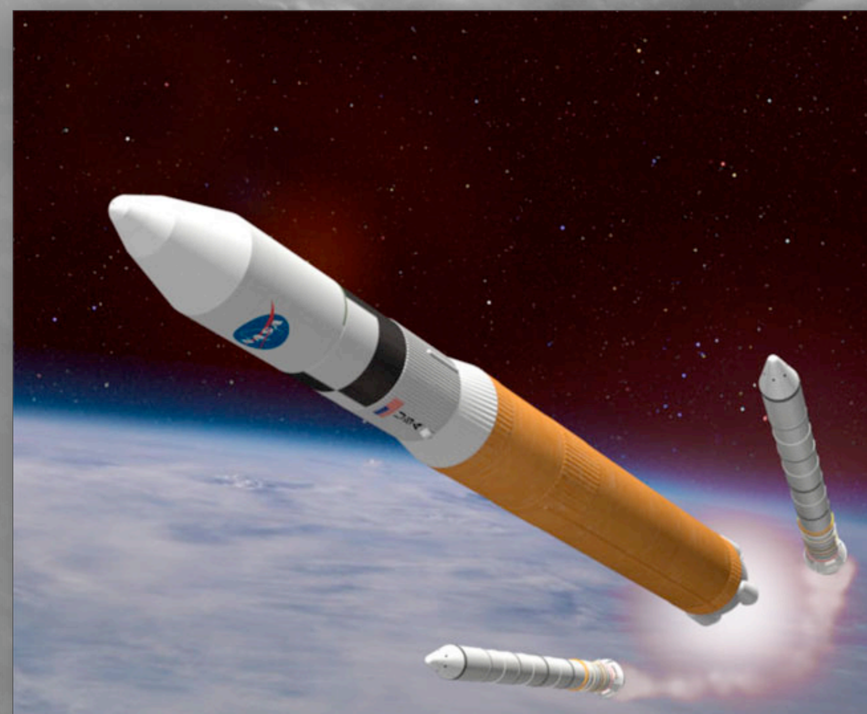




The meeting was organized by STScI in collaboration with JHU, AURA, and NASA, with about 160 participants.

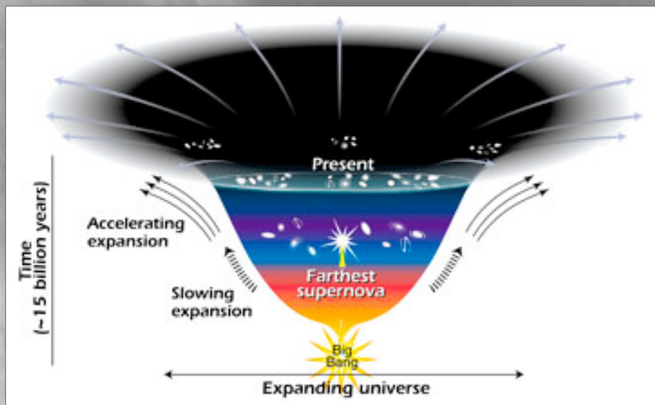
Goals:

- To identify intriguing astrophysical questions for the next two decades and beyond.
- To explore if and how the VSE and the return to the Moon can provide opportunities for significant progress toward answering those questions.

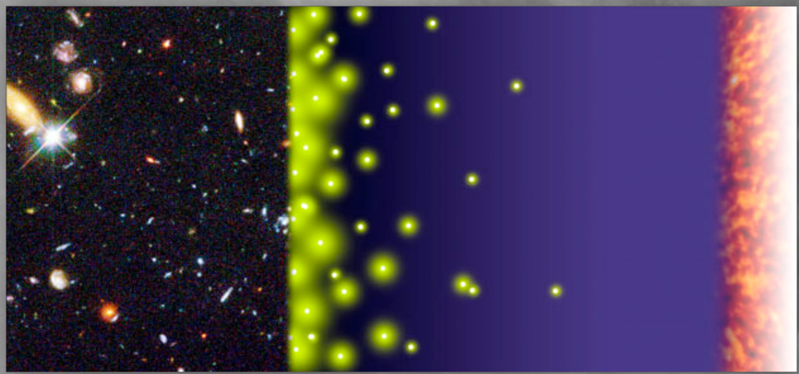


Big Questions in Astrophysics

Why is the universe accelerating?



Which astronomical objects were involved in the “first light”?



Are there habitable extrasolar planets?

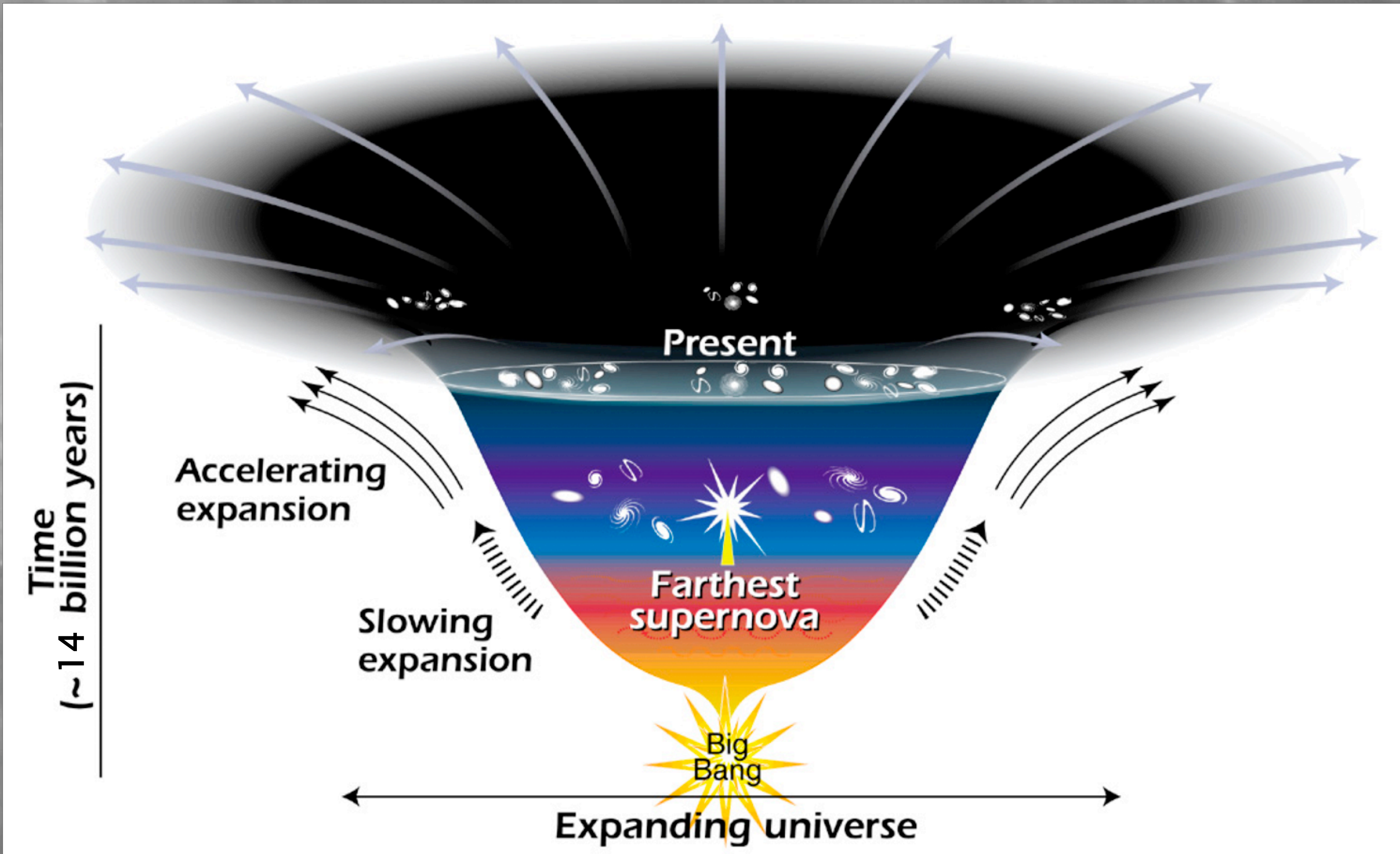
How did galaxies and the large-scale structure form?

The VSE can enable progress in all of these areas of Astrophysics

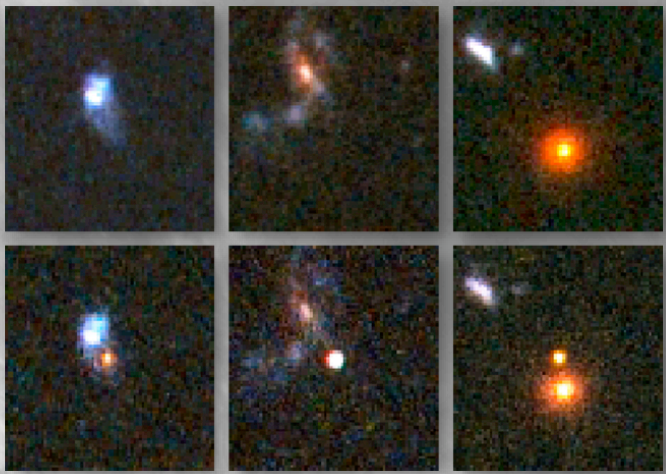
- Capabilities are ideally suited for transportation of large-aperture telescopes (or their components), of the type envisioned for a broad range of future astronomical missions.

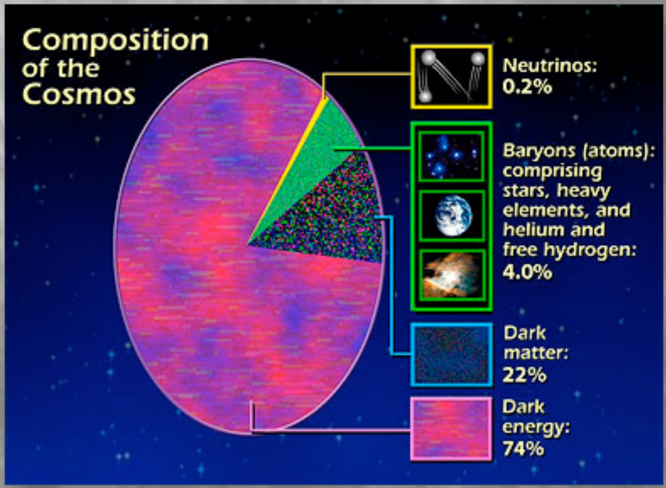
- Progress in some areas will be best achieved by observations from free space (in particular Lagrange points). Some interesting observations can be done from the lunar surface.

1. The Accelerating Universe



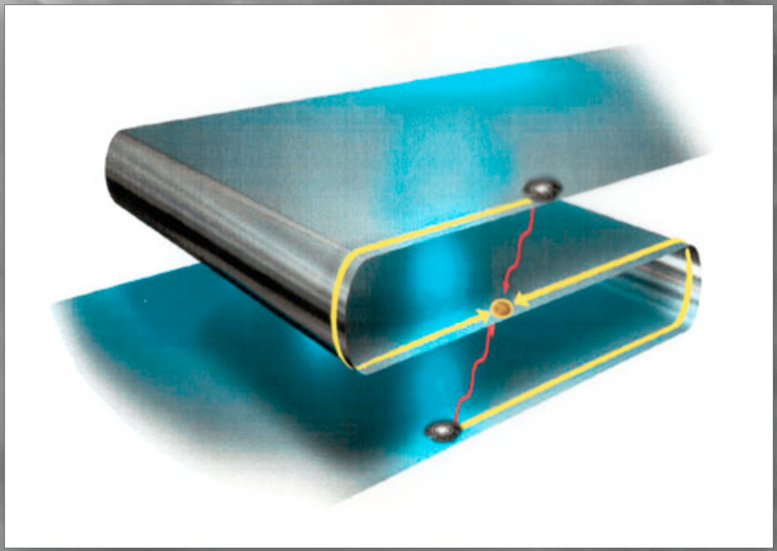
Dark Energy or Alternative Gravity





Currently envisioned to be addressed by wide-field observations from free space (JDEM).

$$H^2 - \frac{H}{r_c} = \frac{8\pi}{3} G_N \left(\rho + \rho_{DE}\right)$$

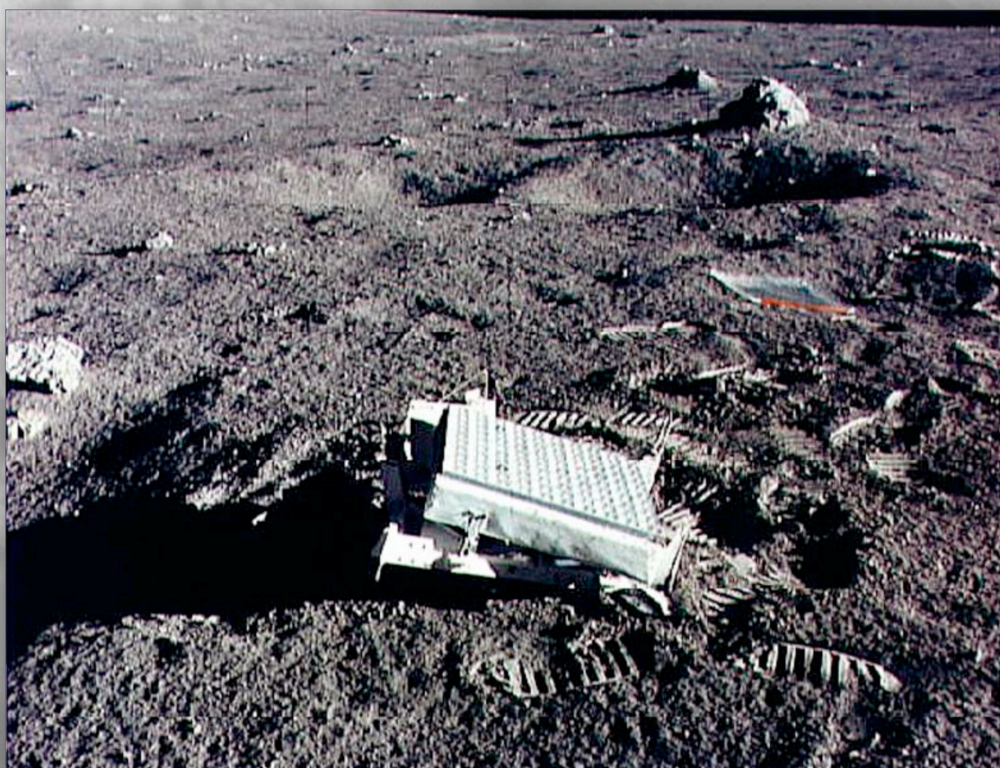


Can be tested by experiments on the lunar surface; laboratory and accelerator experiments.

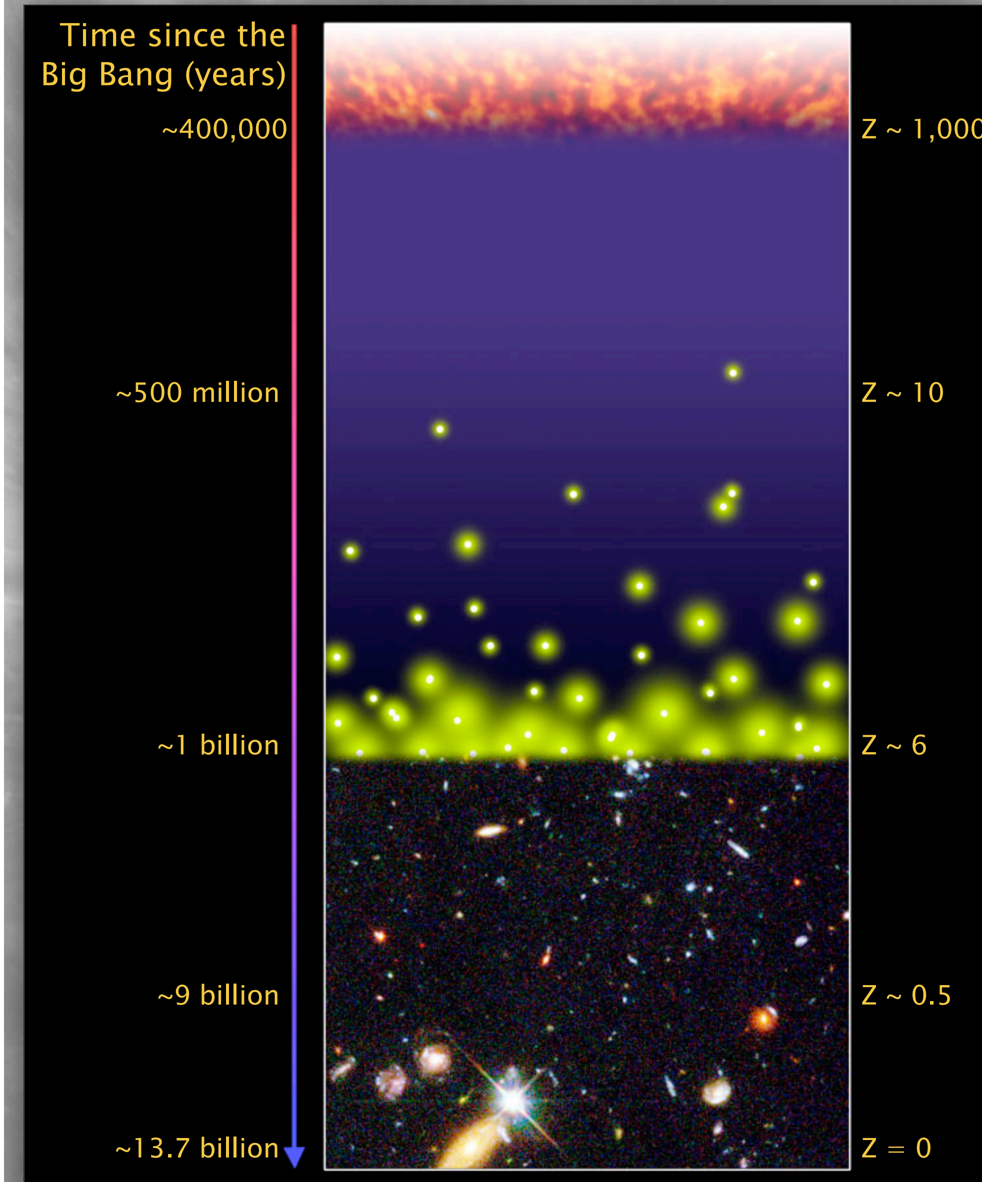
Lunar Ranging Experiments and Theories of Gravity

Measurements of lunar perihelion precession with an accuracy of $\delta\Phi = 1.4\text{x}10^{-12}$ to test alternatives to general relativity.

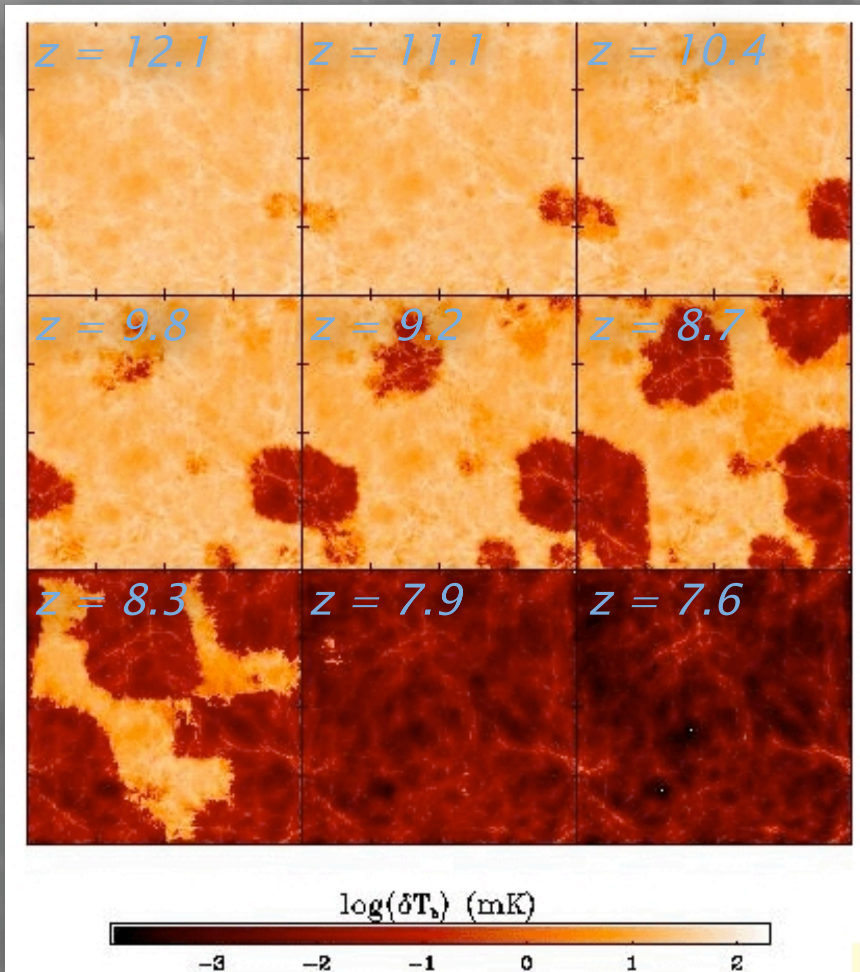
Placing a carefully designed array of transponders expected to achieve desired accuracy.



2. The Epoch of Reionization and Beyond



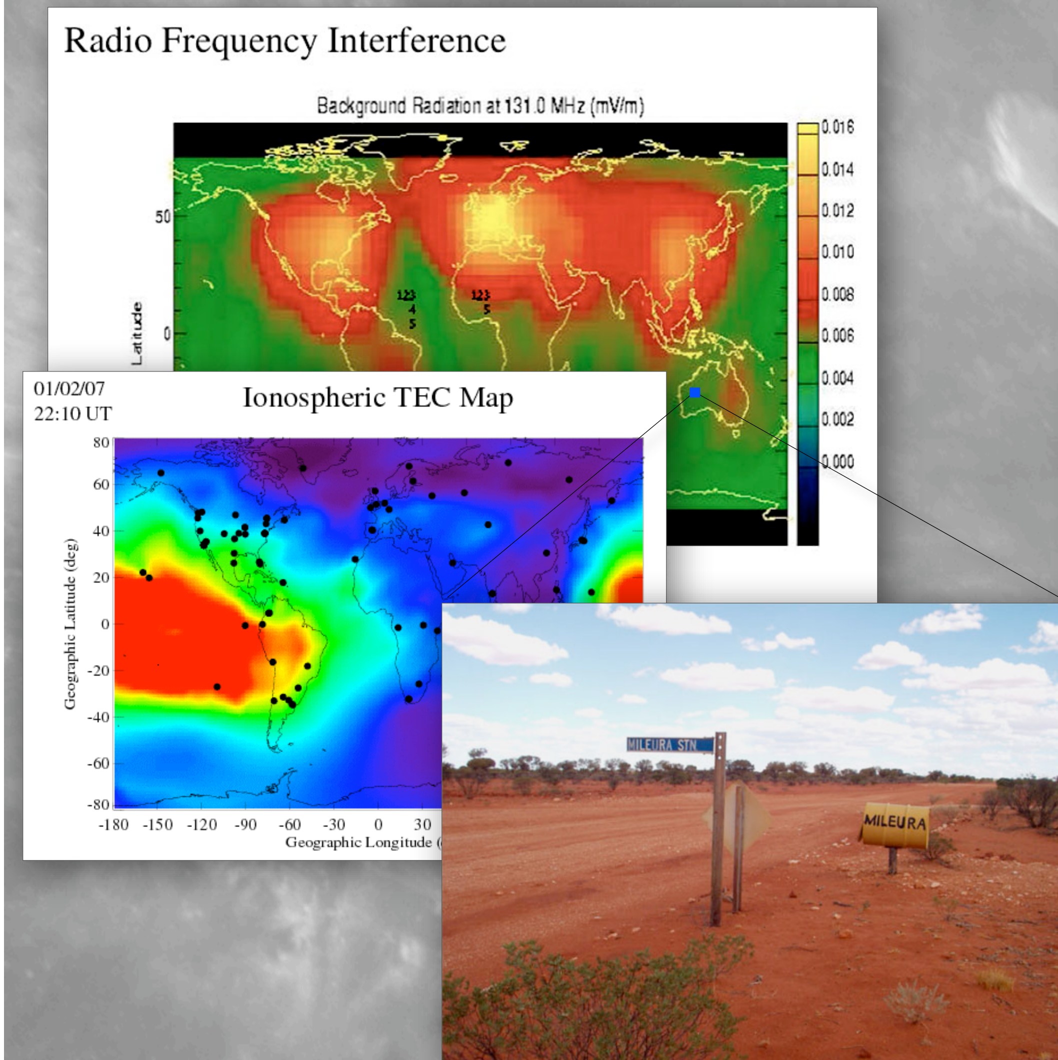
Reionization



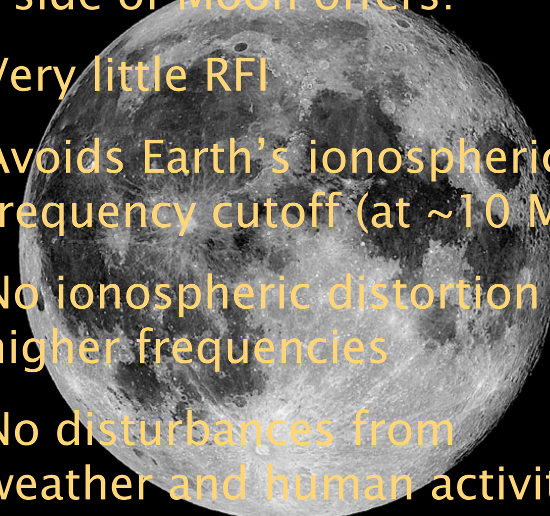
Fluctuations are at about 10 mK

Observations of redshifted 21 cm (in the frequency range 10–200 MHz) neutral hydrogen emission could probe $7 < z < 100$ (100 million – 1 billion years after the Big Bang)

On Earth



On the Moon



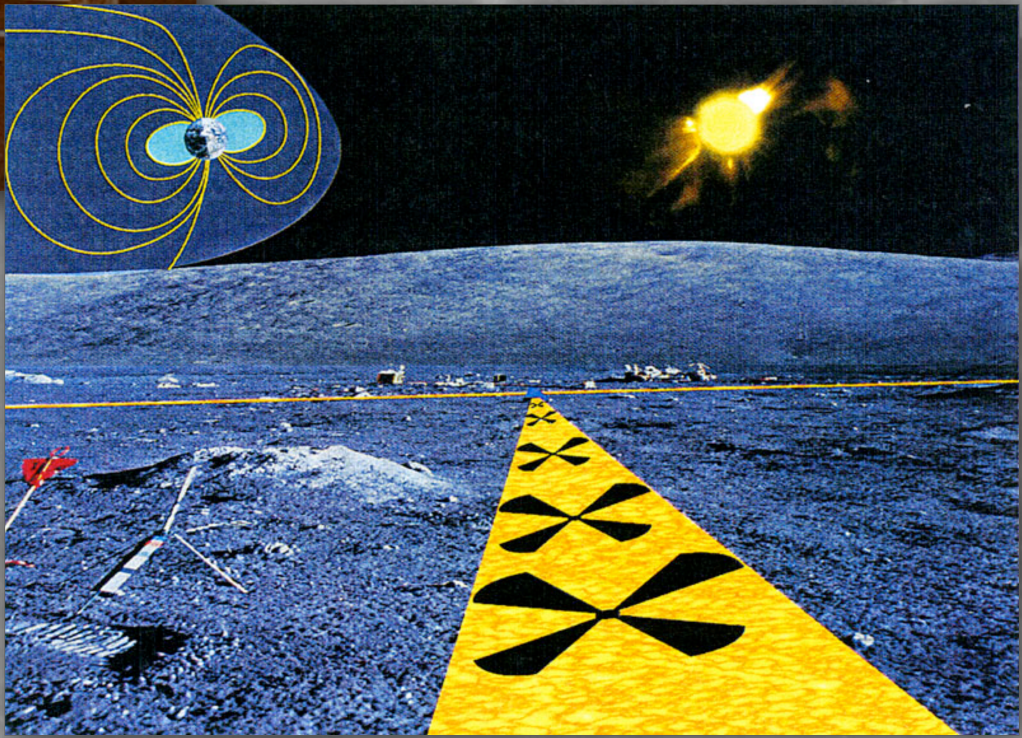
Far side of Moon offers:

1. Very little RFI
2. Avoids Earth's ionospheric frequency cutoff (at ~10 MHz)
3. No ionospheric distortion at higher frequencies
4. No disturbances from weather and human activity.

"Everyone is a Moon, and has a dark side."
– *Mark Twain*

Relatively easy to do?

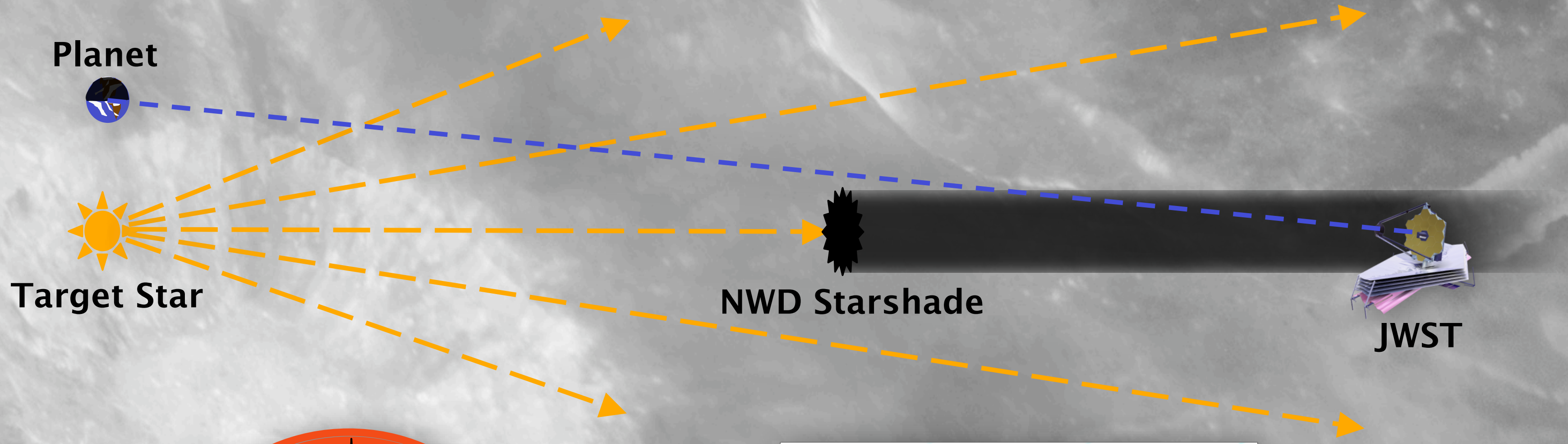
Low frequency radio observations require only lightweight dipoles

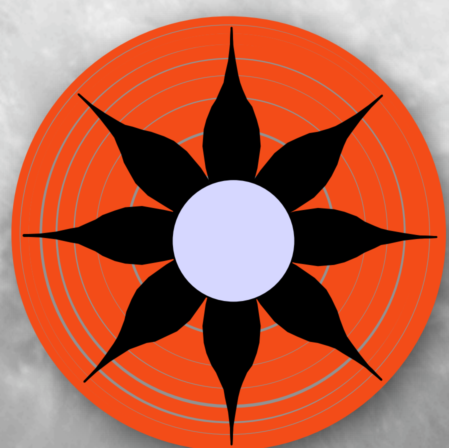


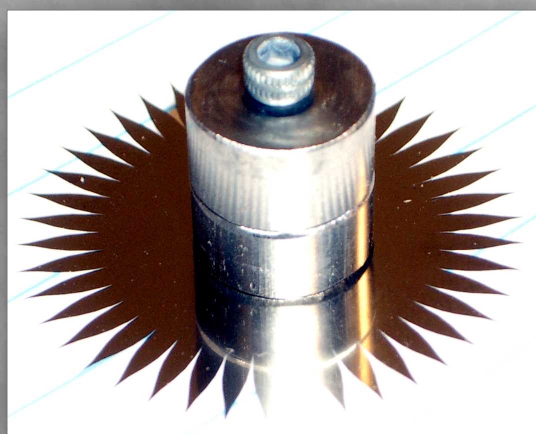
3. Are There Extrasolar Habitable Planets?

a. Potential observations from free space.

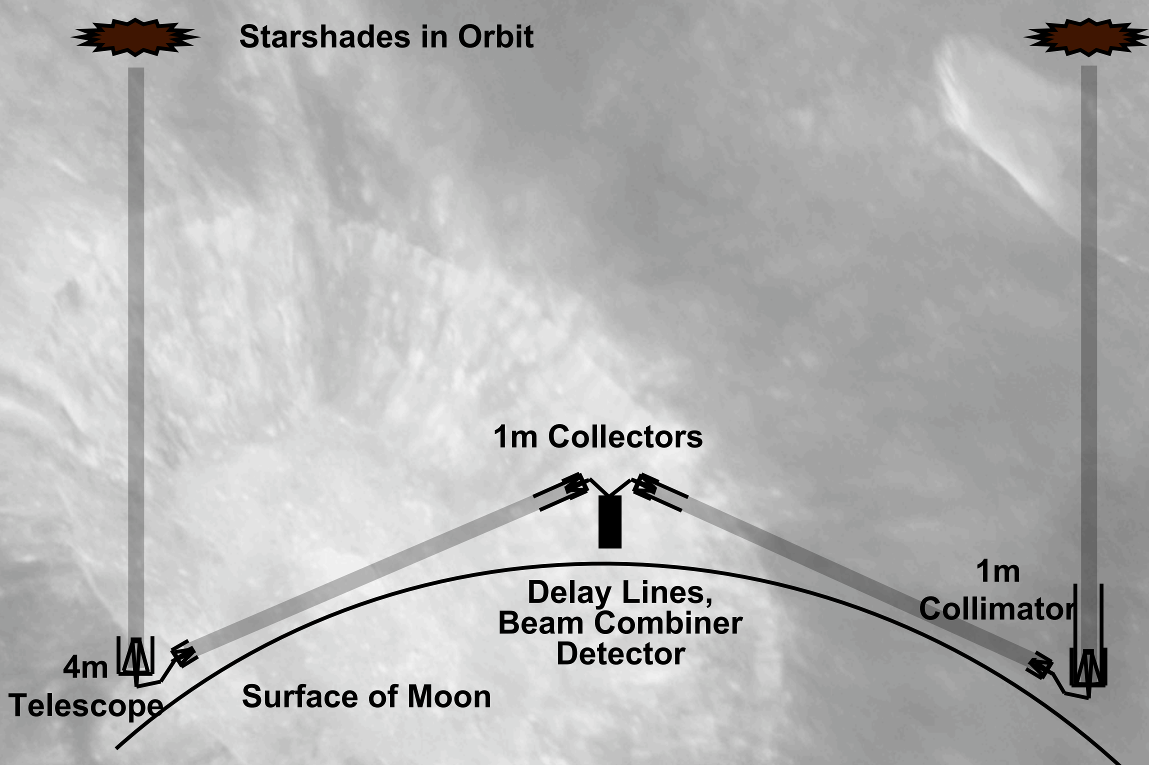
External occulter throws deep shadow over JWST, but allows planet light to pass.

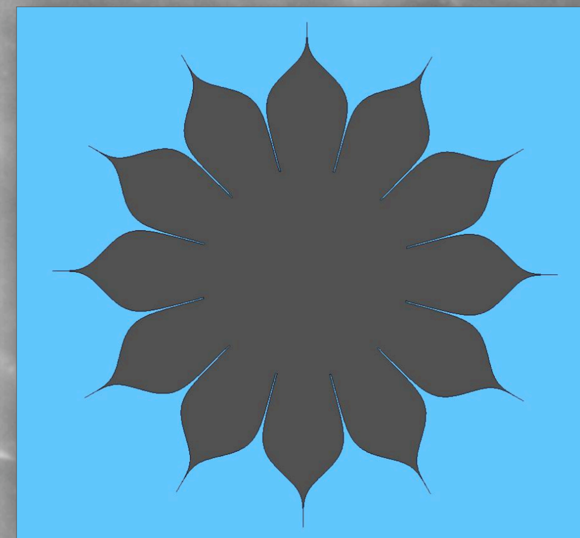


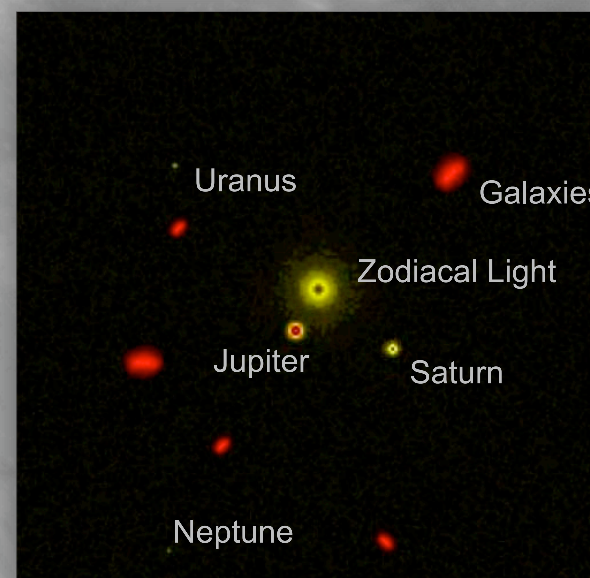




b. Potential observations from the lunar surface?



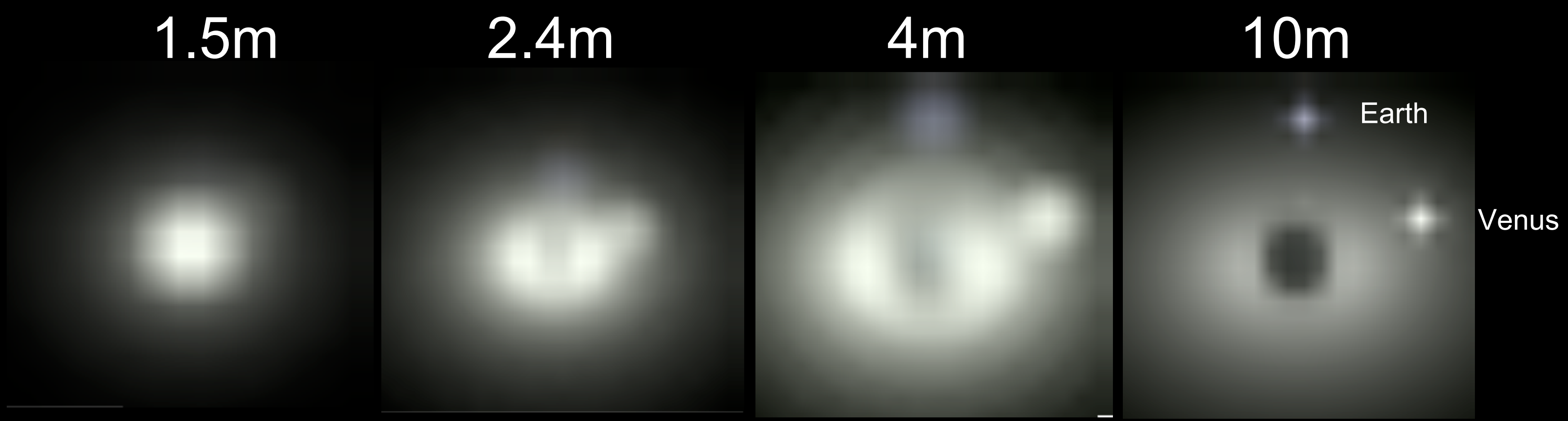




The occulter is 30 m in diameter at a distance of ~20,000 km from telescope

Characterizing Exoplanets

Credit: Web Cash 2008



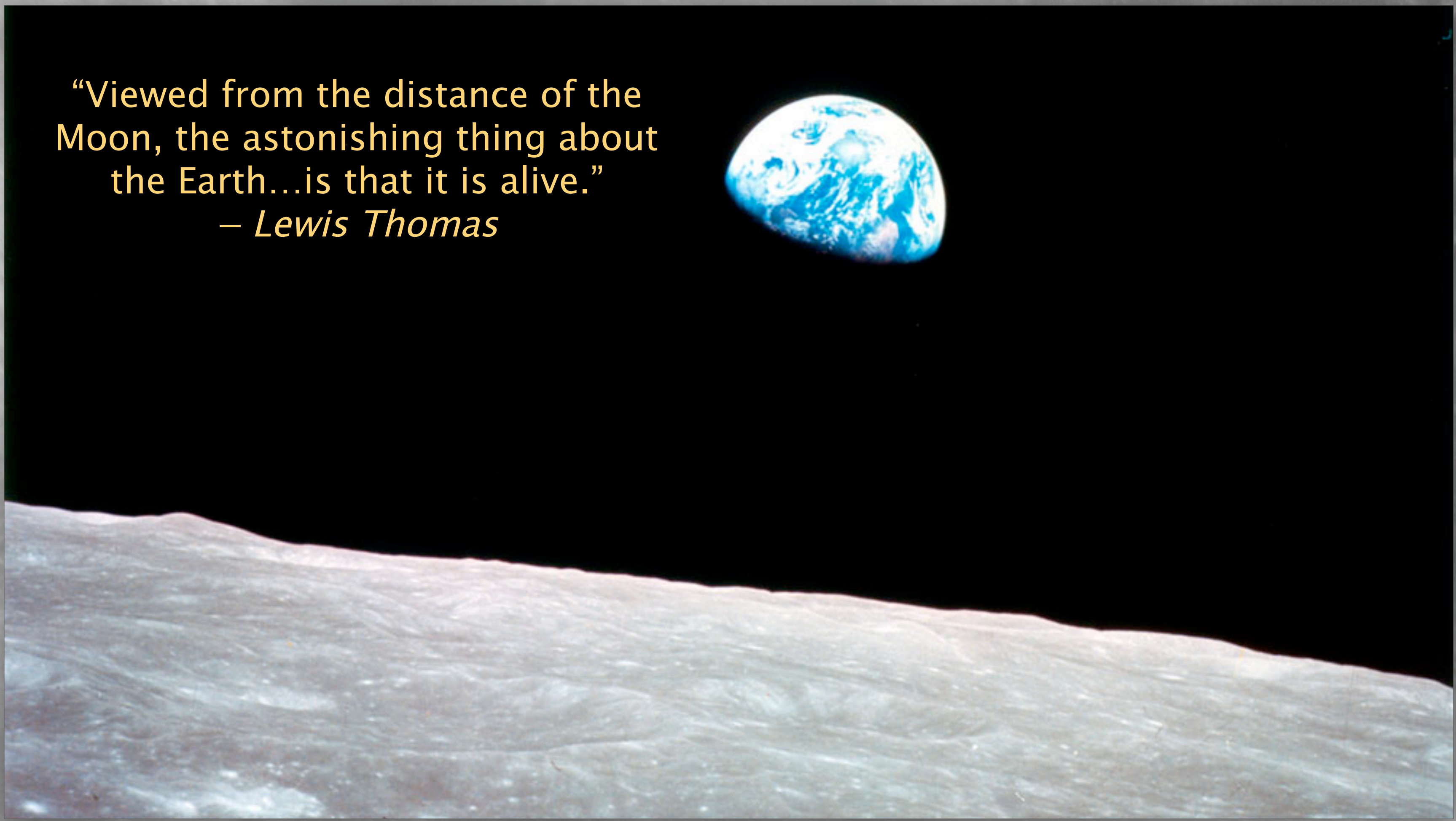
Above: a simulation of our solar system at a distance of 10 pc observed with an external occulter and a telescope with the indicated aperture size. The two planets are Earth and Venus. The challenges of deploying and maneuvering the star shade, however, also increase with increasing telescope aperture. Using a combination of an internal coronagraph and an external occulter may be the optimal solution.

Characterizing Exoplanets: Via the use of an external occulter, one can suppress the light of the central star, enabling the detection of any orbiting exoplanets. Detecting and characterizing these, however, becomes progressively easier with increasing telescope aperture.

Discriminating terrestrial scale planets from their parent star *also* requires angular resolution

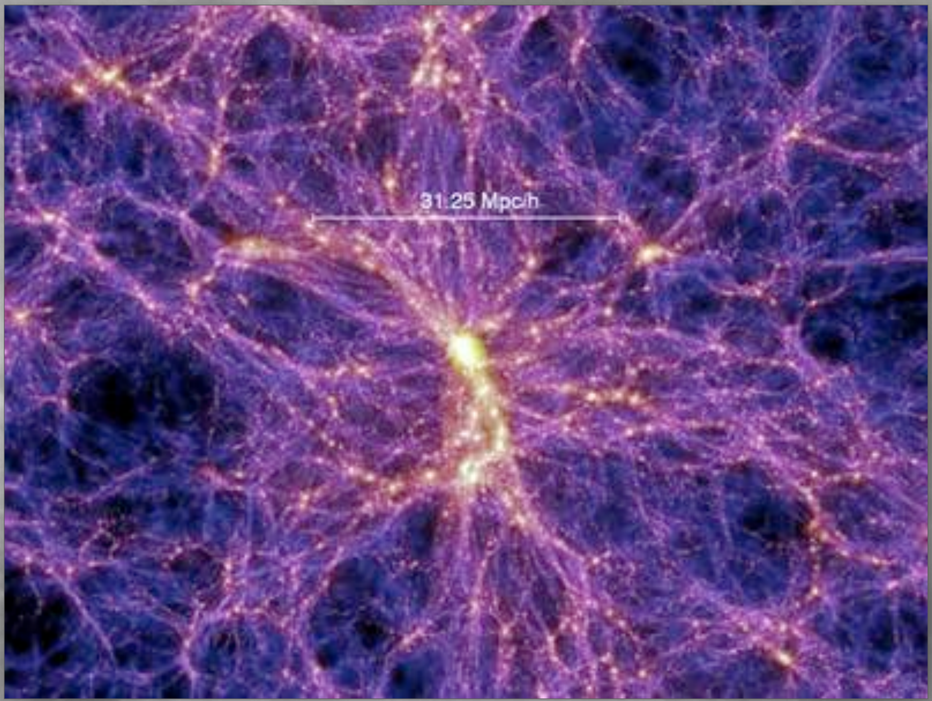
c. What does a life-bearing planet look like?

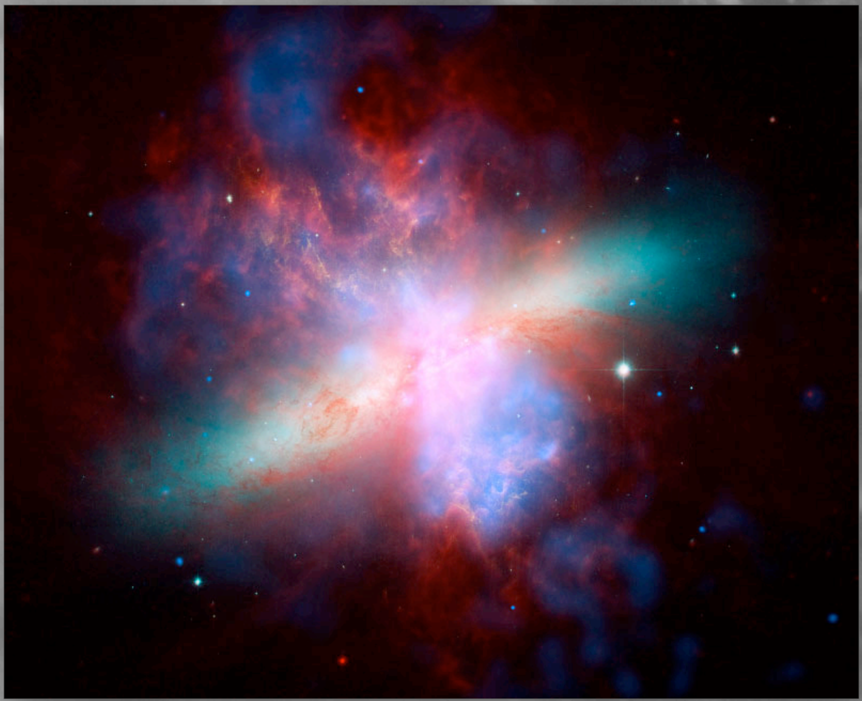
Potential precursor observations from the lunar surface:
A small telescope to observe the Earth to characterize
the time-dependent signature of a life-bearing planet



4. The Assembly of Structure

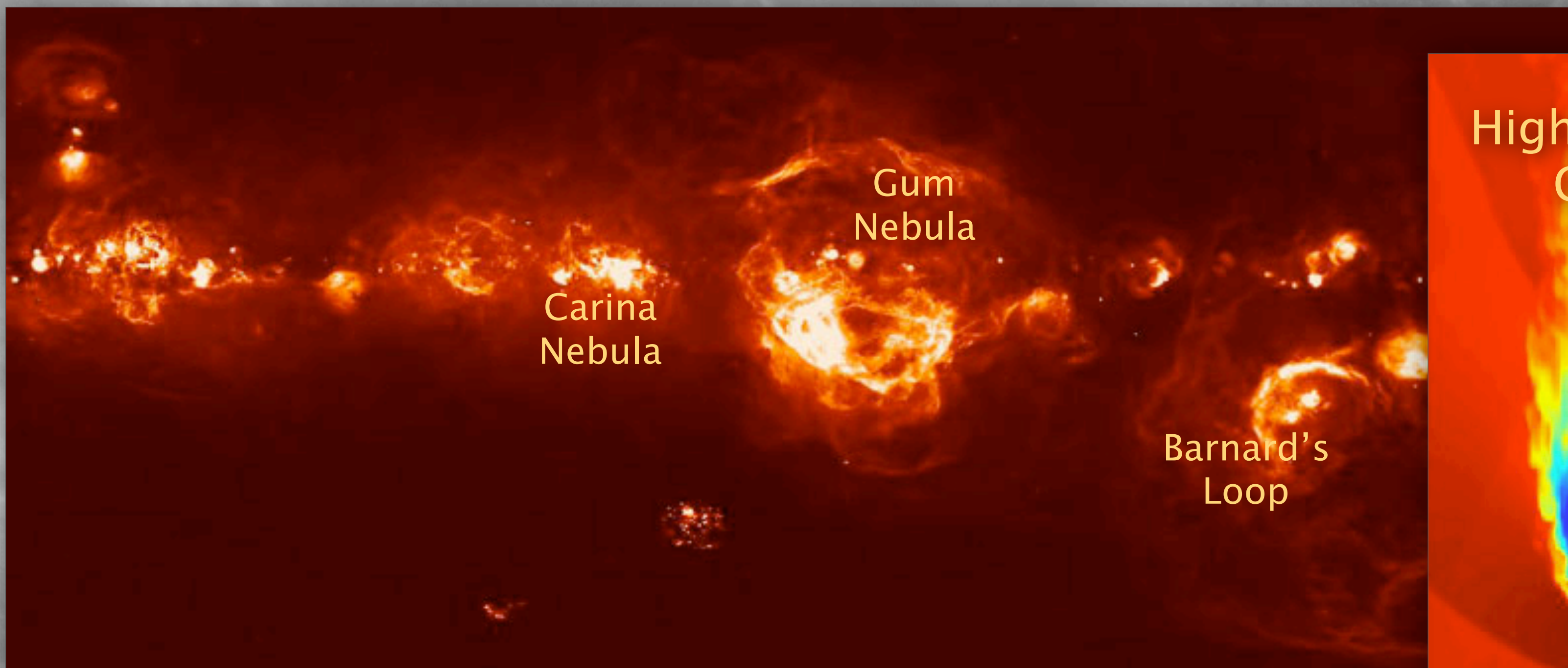
a. Potential observations from free space

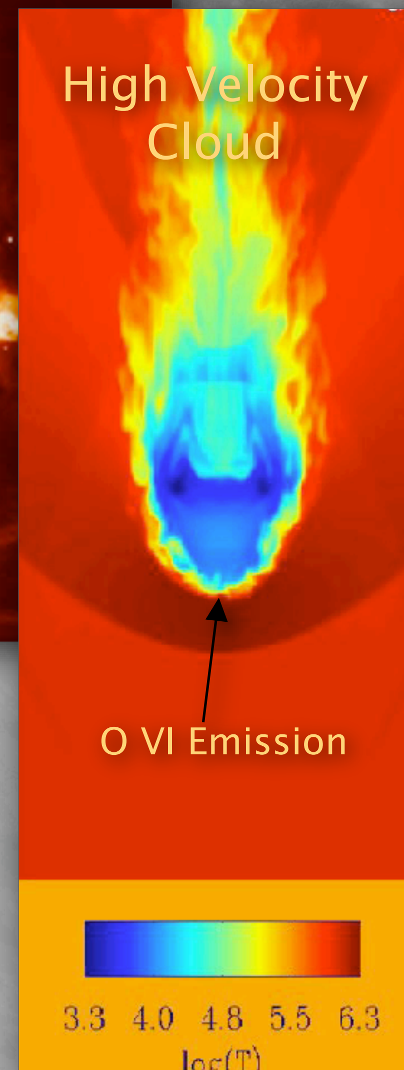




Structure of the cosmic web and the intergalactic medium can be best studied by ultraviolet spectroscopy from L2.

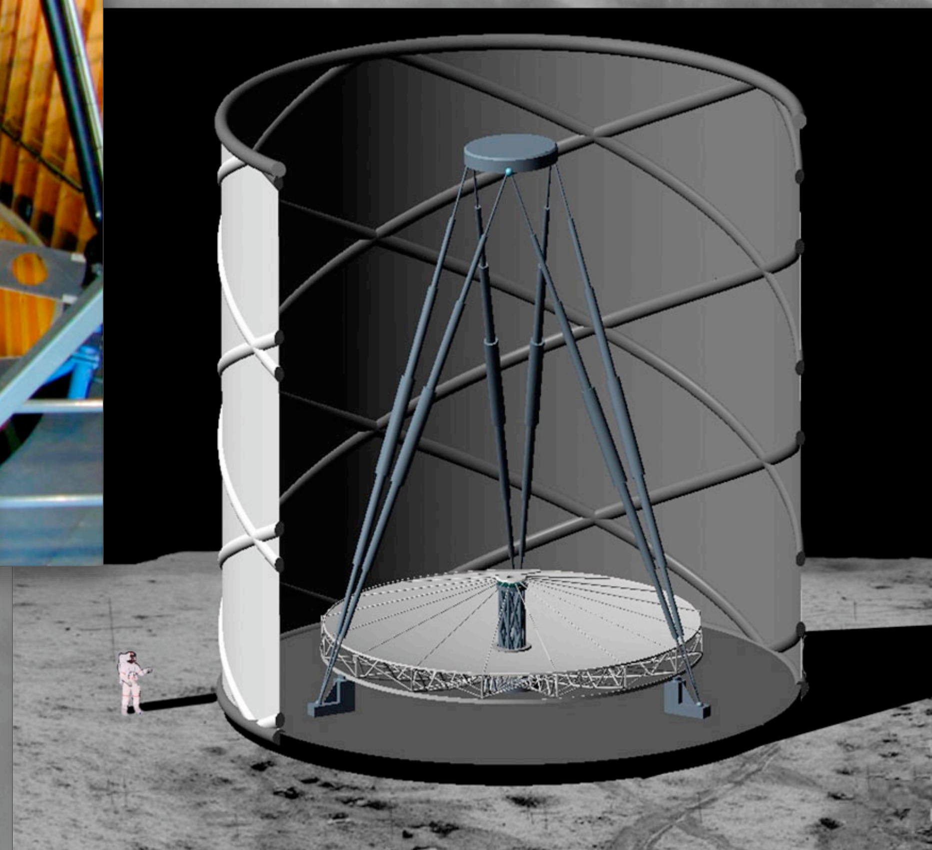
b. Potential observations from the lunar surface: A small far-UV telescope to examine the structure and composition of the hot (T ~ 10^5–10^6 K) Galactic medium





The hot gas is probably the least understood baryonic component of the Milky Way.

c. Deep-field observations from the lunar (north) pole could produce images deeper than the Hubble Ultra Deep Field, to study galaxy evolution

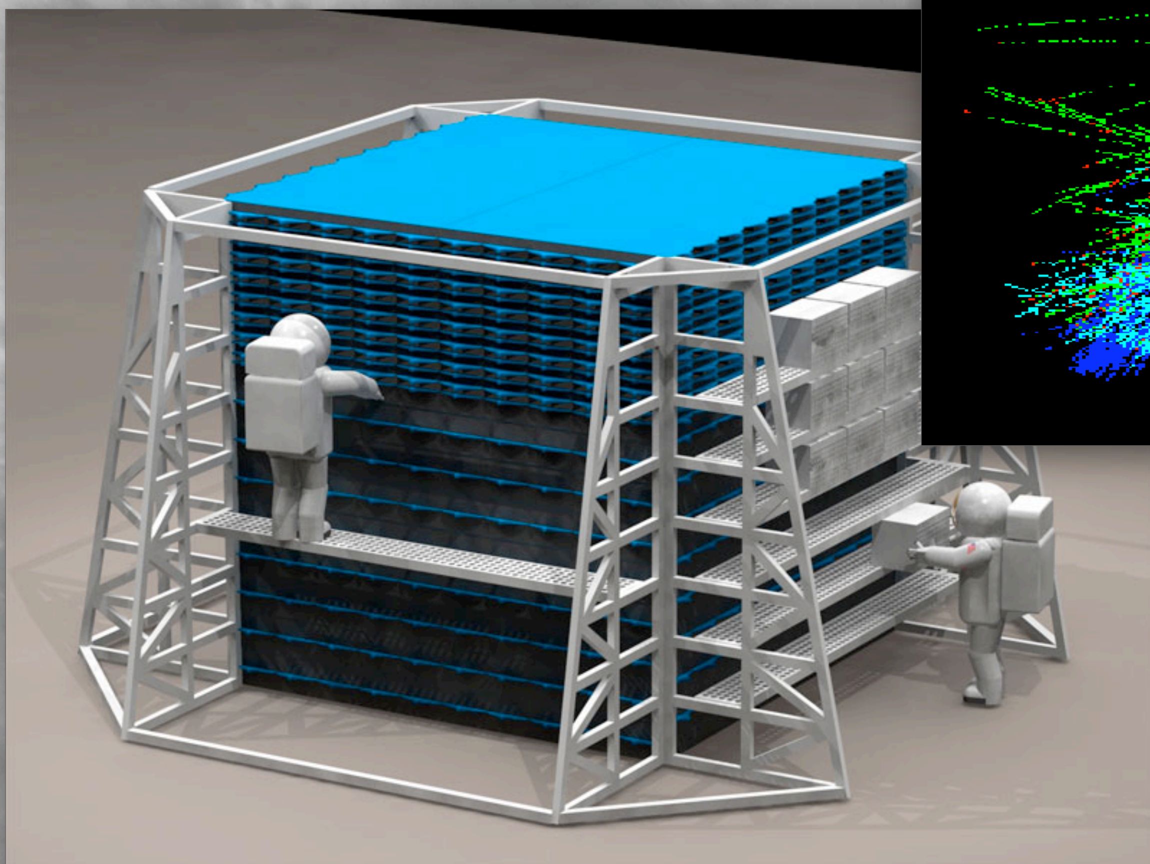


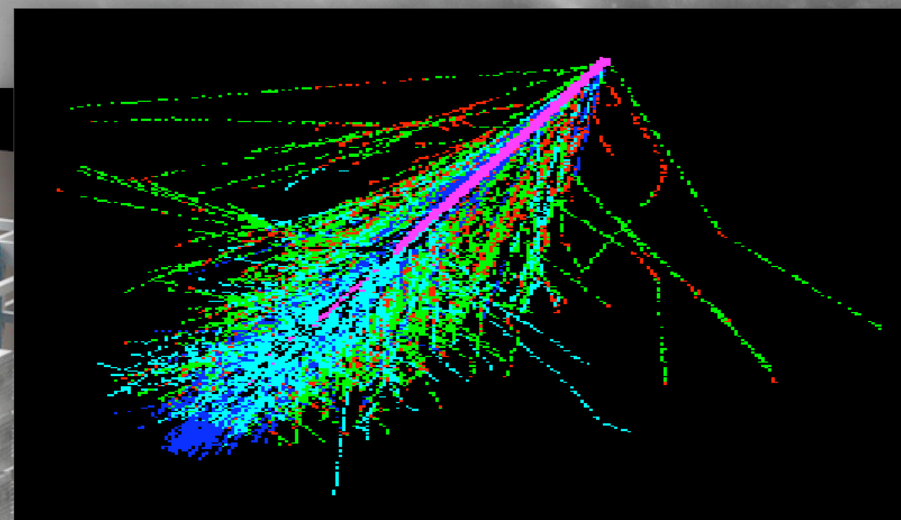
Liquid mirror could be 20-100 m in diameter

A More Specialized Scientific Topic

How are Galactic cosmic rays accelerated?

A calorimeter to study intermediate-energy ($E \sim 10^6$ GeV/particle) cosmic rays



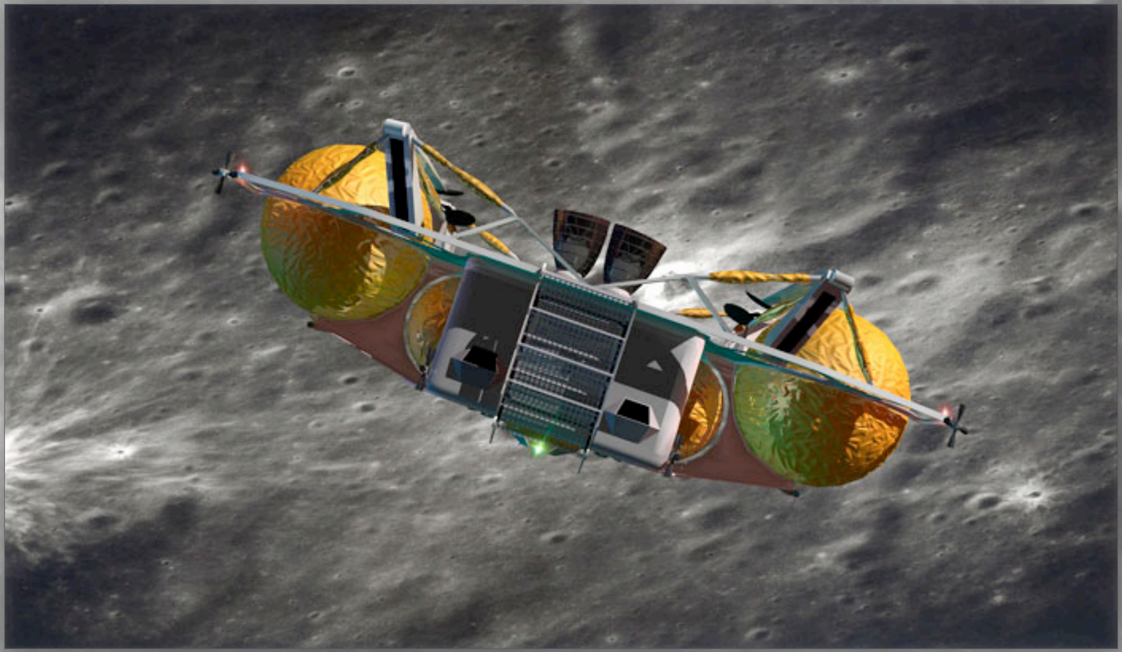


Has to use ~150 tons of layered regolith.

Can detect the primary particles.

CONCLUSIONS

1. The return to the Moon can enable significant progress in astrophysics.
2. We have identified some important astrophysical observations, as well as a few smaller experiments that can be uniquely carried out from the lunar surface.

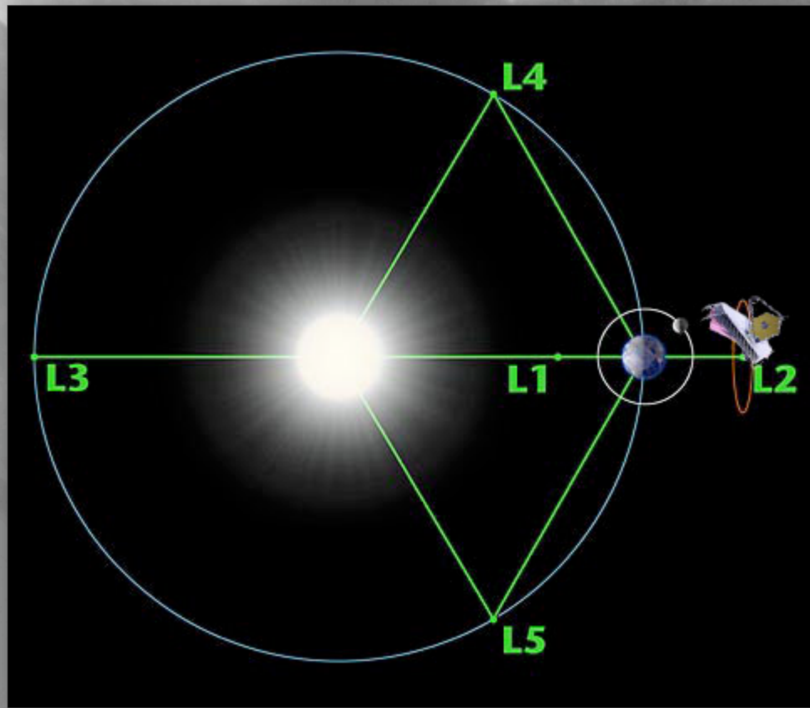


CONCLUSIONS

3. Observations from free space (in particular Lagrange points) offer the most promise for broad areas of astrophysics.

Capabilities in free space include:

- All-sky access
- Diffraction-limited performance
- Very precise pointing and attitude control
- Thermal equilibration and temperature stabilization
- Efficient operations



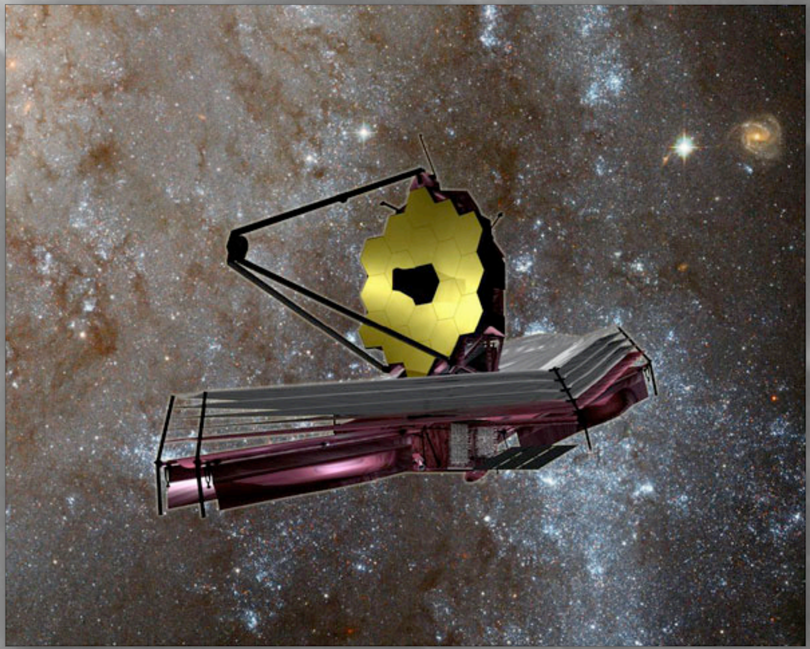
Sun-Earth Lagrange points (not to scale)

CONCLUSIONS

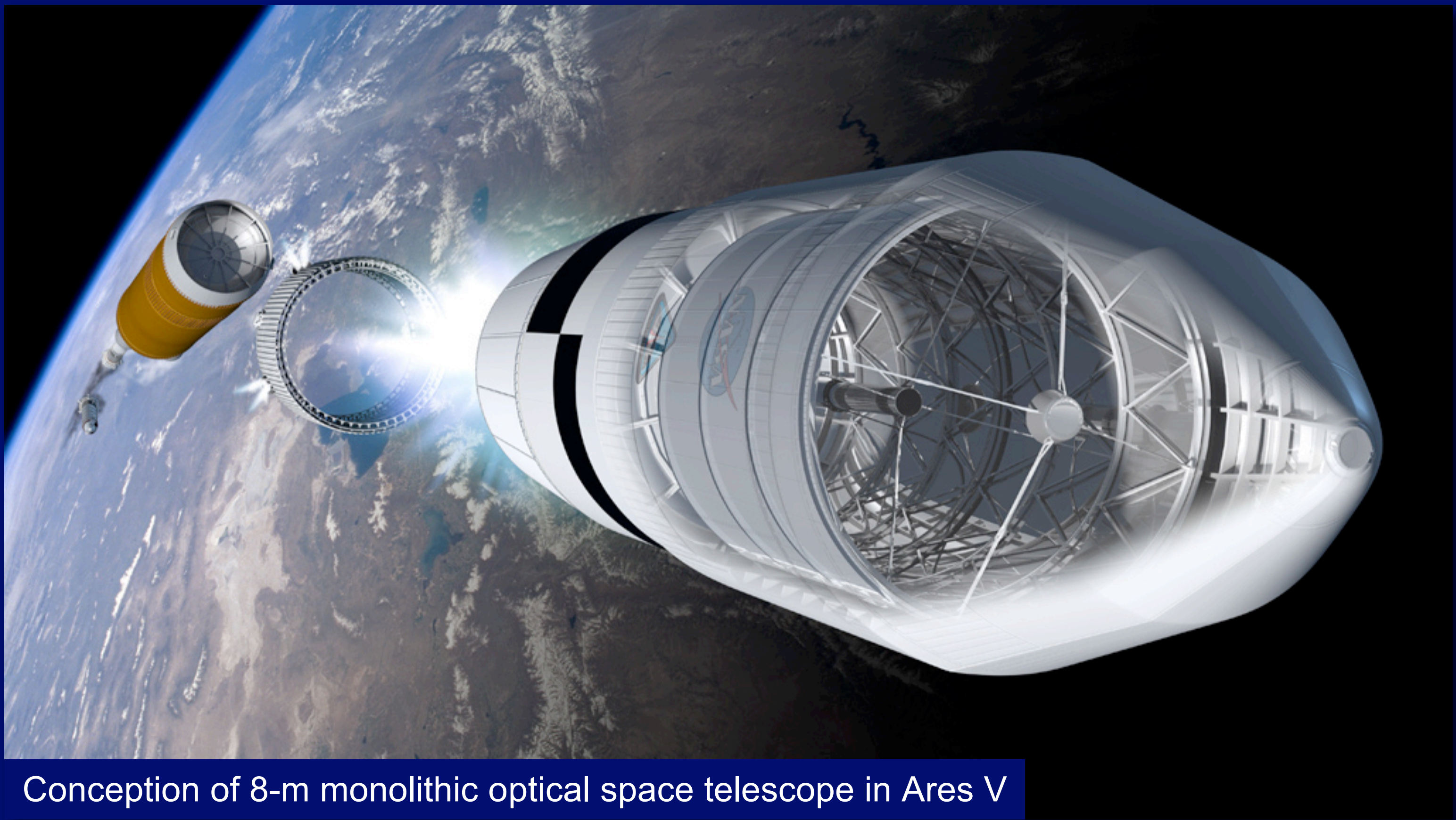
4. The VSE should be planned so as not to preclude — and to the extent possible to include — capabilities that will enable astrophysics from free space.

Capabilities of great interest include:

- Large fairings
- Advanced telerobotics
- EVA capabilities
- High-bandwidth communication
- A low-cost transportation system (e.g. between Lagrange points)



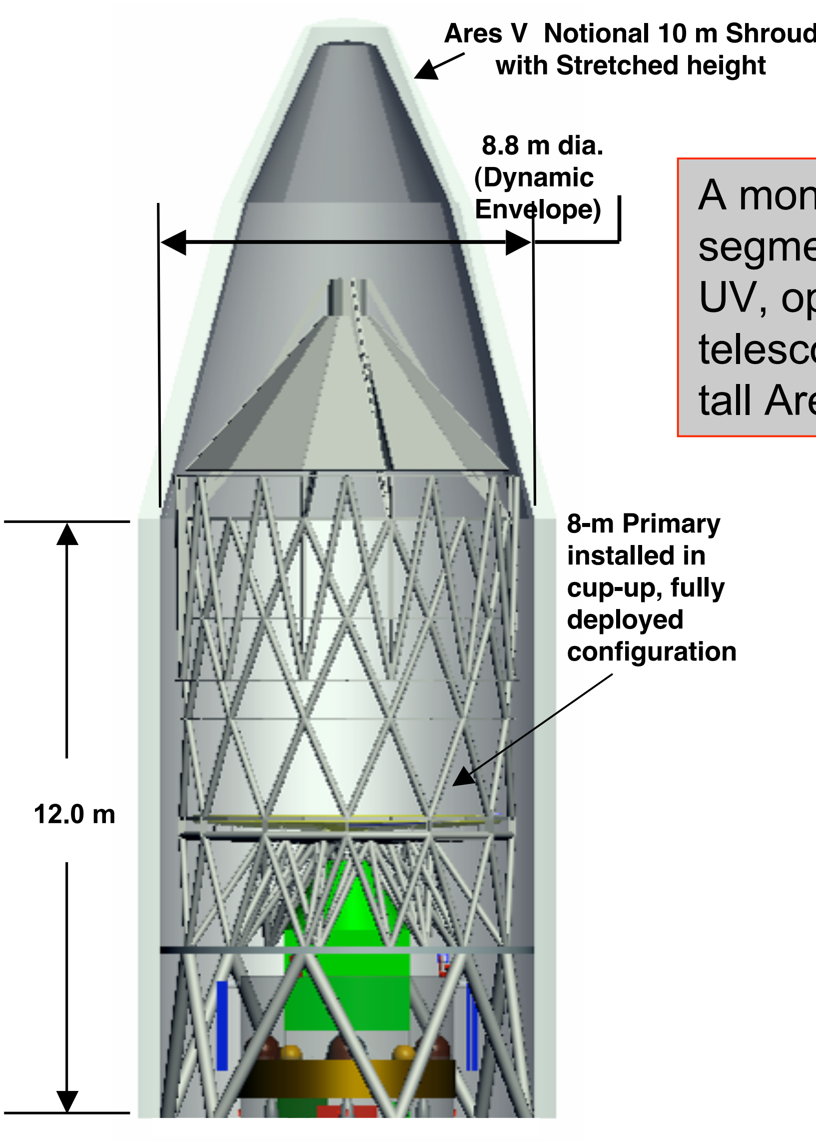
Ares V enables a fully deployed 8-m or folded, segmented 15 - 20m telescope to be deployed in a single launch.



Conception of 8-m monolithic optical space telescope in Ares V

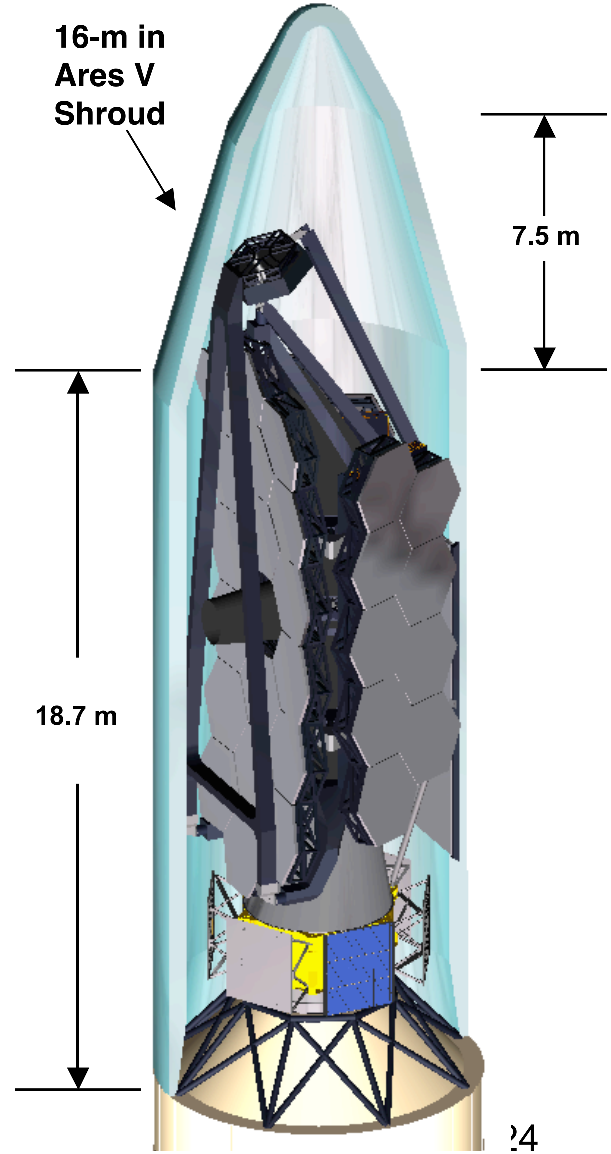
Without Ares V, multiple launches, complex folded optics, and/or on-orbit assembly would be the only alternatives for deploying space telescopes larger than ~7-m.

Launch Vehicle Integration & Packaging



8-m Monolithic Telescope

A monolithic 8-m or segmented 16-m UV, optical space telescope requires a tall Ares V fairing.



16-m Segmented Mirror Telescope

How Do You Take Six Billion People to the Moon?

Matt Bobrowsky, Denise Smith, James Manning, Bonnie Eisenhamer, and the Office of Public Outreach, STScI

The potential for significant science returns exists in our return to the moon. This endeavor also presents a unique opportunity in science education. With proper planning, the Education and Public Outreach (EPO) community can use new lunar science achievements prompted by the Vision for Space Exploration to provide excitement, inspiration, and learning that will revitalize the public's interest in space exploration and make students and the public highly engaged in astronomy and space science. The trip to the moon and the scientific research done on the moon will provide countless "teachable moments" and new, exciting avenues of outreach. EPO professionals will be able to give everyone in the U.S. (and around the world) a unifying, educational "lunar experience."

Motivation

Just as the Vision for Space Exploration will provide new prospects for scientific research, it will also provide new opportunities in education and public outreach. Coupling the new science enabled by the return to the moon with proven education and public outreach strategies will enable us to engage six billion people in the adventure, the science, and the story of the return to the moon.

Goals for Lunar Science EPO Programs

- Engage and excite the public and students about the lunar exploration program through the scientific discoveries made possible by the return to the moon.
- Use lunar-based science efforts and results to inspire and educate both public and student audiences in science, technology, engineering, and mathematics (STEM), spark student interest in STEM careers, and provide new avenues for exploring such careers.
- Provide effective and appropriate access to lunar exploration and science programs for educators, students, and the public.

Planning for the Future

There are important questions to consider if we are going to take full advantage of our return to the moon and the science we will do there.

- How can we translate the adventure into greater public engagement, science literacy, and interest in space exploration?
- How do we get the public to care about lunar-based science and technology (and science and technology in general) — and the entire lunar program?
- How can we relate lunar-based research to the daily lives of people on Earth and help them to feel a personal connection to our return to the moon?
- How do we encourage the public to consider the benefits of going back to the moon?
- How can we help educators to extract teachable moments from our return to the moon, and use the scientific discoveries to improve the teaching of science and technology both in and out of the classroom?
- How can scientists and educators work together to use our return to the moon to increase the likelihood that students will pursue careers in science and technology?

Key Elements to Consider

- **Harnessing new technologies to communicate lunar-based science to the people of the world:** Today, for example, podcasting is a popular medium. We will need to be prepared with whatever communication mechanisms and other technologies arise in the coming years.
- **Building program-wide commitment to communicating science to the public:** Scientists, engineers, and educators will need to work together to identify and include elements that will increase our ability to engage the public.
- **Providing quick access to scientific results and data:** Just as Hubble Space Telescope early-release observations immediately demonstrate to the public that new instruments work and enable new science, we will want to ensure universal access to at least some of the science. One cannot underestimate the impact of enabling the public to see new scientific results at the same time as the scientists see them.
- **Creating mechanisms for public access:** Providing the means for individuals to directly experience lunar-based science will facilitate ownership in and commitment to further learning and exploration. Possibilities include setting up cameras on the moon to provide live video to the Web, and putting a small remotely operated telescope on the moon for public use. This could lead to excitement and engagement in various venues, including science museums, planetariums, classrooms, and the mass media.
- **Identifying the elements of the mission and the science that provide unique opportunities for education and public outreach:** See the accompanying poster by Waller et al.
- **Tailoring our efforts to specific target audiences:** To increase the likelihood the programs will be used and used effectively, it is essential to consider the needs of our audiences. For formal educators, it will be critical to demonstrate the connections between lunar-based science and national education standards. Cultural considerations are also essential in bringing lunar-based science to diverse populations.
- **Leveraging education and public outreach strategies proven to be effective during more than a decade of NASA mission programs:** We will use resources and lessons learned from existing education and public outreach programs to take six billion people to the moon!

Conclusions

Through innovative and coordinated efforts to engage the people of Earth in a new lunar-based science adventure, students, educators, and the public can gain a greater understanding of lunar-based science and technological concepts and can attain a deeper appreciation for the process of science — critically important at a time when there is so much misunderstanding about what science is and why it is so important to our future.

Educators will be able to take their students on virtual journeys to the moon and, with our help, will engage students with exciting, new scientific results and resources to improve STEM teaching, enhance science and technology curricula, and encourage the consideration of STEM careers.

This is a science education opportunity not to be missed, and this is the time to start planning.

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